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AGRICULTURAL MEMORANDUM 1048

THE USE OF CLEAR POLYTHENE MULCHES OVER YOUNG CARROTS:- SOME TRIAL RESULTS

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Summary

The main purpose of this memorandum is to present some results obtained from trials at Arthur Rickwood Experimental Husbandry Farm in the spring of 1982. The trials involved the use of several different kinds of material for the purpose of mulching both young and overwintered carrots, but this paper is confined to the mulching of young carrots by clear polythene with the aim of increasing temperatures, and therefore promoting growth.

Results obtained show that surface temperatures underneath the polythene are increased by up to 15°C on calm, sunny days. This gives rise to a doubling of the accumulated temperature above 6°C over that which is observed on nearby bare soil. The accumulated temperature in the soil at a depth of 10 cm is also raised considerably. There is little or no increase in the surface temperature under the polythene at night.

Explanations are put forward regarding the observed increase in surface and soil temperatures, the behaviour of the soil temperature during the later stages of the experiment and at mulch removal is discussed in some detail.

Introduction

The use of clear polythene mulches to bring forward spring carrots is now quite widespread. Presumably, therefore, carrot growers know from experience that clear polythene increases the temperature around young carrots considerably. However, the level of temperatures excess does not seem to have been quantified under currently used mulches, and furthermore the reasons why a temperature excess is observed may not be properly understood.

The results presented in this memorandum are taken from trials conducted in the spring of 1982, in which a variety of mulch materials were used.

The Surface Energy Budget for a Mulched Surface

Figure 1 attempts to show all the significant contributions to the energy budget. These essentially consist of a net radiative gain or loss, which is dissipated or balanced by sensible, latent, and soil heat fluxes. In a steady-state situation, ie, with no change of surface temperature, this can be written as,

$$R_N + H + LE + G = 0$$

(Refer to Figure 1 for definitions of the terms).

Should there be an imbalance in the energy terms the surface temperature changes in such a way as to restore the equilibrium. (Note that all the terms depend on the value of the surface temperature, except for LE).

Now let us examine the individual energy terms in greater detail, beginning with the net radiation. By day this will be positive, in the sense that energy is added to the surface, because the solar radiation far outweighs what the surface is emitting in the infra-red part of the spectrum. The net gain at midday on a clear day in April will be of the order of 400 Wm^{-2}. At night there is a net loss because the ground continues to radiate outwards to a cold sky, whilst obviously there is no input. On cloudy nights, this loss may be minimal, but on clear nights it will be of the order of 50 Wm^{-2}.

The other three terms are responses to differences of temperature or vapour pressure. For instance if the surface temperature is greater than that, say, at a 10 cm depth inthe soil there will be a flux of heat through the soil to that level by conduction. Heat is lost from the surface to the air by convective processes, and this sensible heat loss is proportional to the temperature difference between the ground and the air, and also the windspeed. Finally, latent heat exchanges are dependent on the presence of water and conditions conducive to its evaporation or condensation. Evaporation results in large amounts of energy being used whilst condensation processes release energy at the surface.
Having established what the contributions to the surface energy balance are, the question to pose now is, how does a mulch modify these energy exchanges?

First of all, the new surface intercepting the solar radiation could reflect a greater or lesser quantity of it, and will also possess a different emissivity, resulting in a new amount of long-wave emission. Consequently a different value for the net radiation term might be expected.

Secondly, the mulch could be transparent or opaque to the radiation, and therefore in the latter case, the surface would receive no direct radiation at all.

For new, clear polythene the transmissivity is about 90% in the shortwave and 70% in the long wave. Therefore there will be a small net absorption of energy due to the transmissivity difference, ie, the so called 'greenhouse effect'. However, this mechanism for raising the temperature under the mulch is of secondary importance, as will be demonstrated next.

The major effect of a mulch is to modify the partitioning of the energy from the net radiative gain during the daytime. A mulch has the effect of shielding the surface from the free wind and inhibiting exchange of moisture with the air. The consequence of this is to diminish the magnitude values of H and LE, and to balance the budget equation the surface temperature must rise, and as a result the magnitude of G increases.

Mahrer (1979) has presented results from an experiment in Israel where the soil temperature at a depth of 5 cm was measured in wet and dry soil under clear polythene mulches, and compared to bare control plots. The dry soil under polythene showed a 3°C increase over the dry bare soil, but the mulched wet soil showed a 9°C increase over the wet bare soil. This illustrates very nicely that heat otherwise used for evaporating moisture is used for heating the soil under a clear polythene mulch.

Experimental Procedure

The experiment was carried out at Arthur Rickwood Experimental Husbandry Farm as part of a larger series of trials in the spring of 1982, in which the effects of putting clear and opaque polythene, and straw mulches over young and old carrots were monitored. These followed on from experiments in 1981 reported by Cook (1981). The aim with the clear polythene was to enhance the growth of young carrots by raising their temperature.

A number of trial plots were used, some of which contained young carrots covered with clear perforated polythene, while others were left bare. Thermistor probes were used to measure temperature at the surface, at a 10 cm depth, and at a 30 cm depth in both situations. (Surface probes did, of course, possess radiation shields, which were of the 'saucer screen' type). Outside the plots a mast was set up with a solarimeter at a height of 3 metres, and an anemometer at 2 m, along with wet and dry - bulb temperatures. The readings from all these sensors were recorded at 15 minute intervals on a Microdata 1600L datalogger, before being transferred to a computer for processing. For ease of interpretation the readings were averaged over periods of 4 hours, ie 6 periods in each day. The figures quoted in this paper will therefore have any random errors minimised by the averaging process, so that the bulk of any errors present will be due to systematic errors in the sensors and their signal conditioning circuits. It is unlikely that these will result in total errors greater than ±0.2°C in temperature.

The experiment was conducted during the period from February to mid-May. The polythene was removed on day number 125, (ie 5th May). It should be noted that the kind of mulch referred to here is of the 'floating' type.

Results

The effect we are looking for is a temperature excess underneath the polythene mulch as compared with the bare soil plot. As we have seen from the 'Surface Energy Budget' section, this is likely to be influenced by solar radiation and windspeed. The readings were processed with this in mind, and some of the results are presented in Figures 2 and 3. It is readily apparent from these that a large daytime excess of temperature under the mulch is observed, and that this is strongly related to the amount of

solar radiation impinging on the mulch. The next obvious point to make is that the excess is modified by the prevailing windspeed. For instance, on days 105 and 106, (see Figure 2) the temperature difference reaches 12°C when the windspeed is only 4 knots, but on day 103 the solar radiation is almost as great when the windspeed is 11 knots and yet the peak difference is only 6°C. So, just comparing days 103 and 105, it appears that doubling the windspeed halves the temperature difference. This effect is significant, because it shows that the mulch has not prevented heat loss by forced convection from the surface, or arguably the higher windspeeds encourages some evaporation of water from the mulch/carrot/soil surface system via the perforations. The question of how much net moisture is lost through the mulch is a difficult one to quantify. Rickard (1979) suggests that the rate of water loss in the spring under a plastic mulch with four per cent perforation may be up to 1.7 times as much as that from an unmulched area. However, on the same page as that statement is a comment about the heavy layer of condensation that forms on the underside of the mulch, accompanied by a photograph to illustrate the point. If a significant amount of net evaporation does take place from the mulch, it is hard to postulate a sensible mechanism for the observed increase in temperature.

Figure 3 shows a spell of windy weather which persisted through the nightime. In this instance, it can be seen that the temperature at the surface under the mulch actually fell below that of the bare soil plot. This is because the surface under the mulch is sheltered from the beneficial effects of the mixing taking place in the boundary layer which is tending to bring warmer air downwards. Figure 4 is an attempt to show the relationship between the temperature difference at night and the windspeed. The inference is that windspeeds above 4 knots at 2 metres produces higher temperatures on a bare soil surface than under the polythene. This 'negative excess' appears to reach a limit of -1.3°C ± 1°C. This has no significant implications for the growth of young carrots however, as the effect is quite small, but the fact the temperature difference is close to zero at night should be borne in mind by any grower hoping to protect frost sensitive plants with polythene mulches.

Carrot producers will be most interested in how much extra growth and development they can induce with a clear polythene mulch. This should be a direct function of the accumulated temperature, and for carrots it is believed that 6°C is a suitable base. In Figure 5 accumulated temperatures above 6°C are presented as a running total for the bare soil surface, and also as the difference between this quantity and the value for the mulched surface. The two lines are almost coincidental which shows that the polythene has practically doubled the accumulated temperature above 6°C at the surface, and therefore by implication has doubled the rate of development of the carrots. It should be stressed that this is a surface measurement, which would be expected to show the greatest daytime excess.

As outlined in the earlier section, one of the consequences of a clear polythene mulch is to the raise the soil temperatures. This effect was clearly shown in these results. At 10 cm the peak excess on any given day was 3°C, with a minimum generally of about 1.5°C. (Note that the daily peak lags behind that of the surface). Not until the later stages of the experiment did the temperature difference at 10 cm between the mulched and unmulched plots become zero at any time of the day, which means that although the magnitude of the excess does not match that of the surface, the integrated excess over a 24 hour period is still large. Figure 5 also shows that the accumulated temperature benefit provided by the mulch at a depth of 10 cm is considerable; by the time the mulch was removed, it had an advantage of 80 degree days above 6°C over the bare soil plot. Notice that when the mulch is removed, the daily accumulated temperature excess immediately becomes negative, showing that the soil temperatures under the clear polythene

are falling below those of the bare soil plot. This is in contrast to the surface which immediately assumes the temperature of the nearby bare soil surface.

The behaviour of the temperature difference at 30 cm is even more interesting. In this case, it goes negative on daynumber 111, ie 14 days before the mulch is removed. A marked downward trend can be discerned from daynumber 100, whereas previously it had been around 1.5°C ± 0.5°C from the time the mulch was in place. This is shown in Figure 6. Between daynumber 100 and 125 the surface temperature under the mulch is still showing as large a temperature excess over the bare soil as it did during the early phase of the experiment, so the implication must be that the cooling relative to the bare soil plot is taking place from below. The further obvious conclusion would seem to be that the bare soil plot is warming up faster than the mulched plot at 30 cm. Why is this? To find a possible explanation we need to consider the annual soil temperature cycle. At some depth there is no variation in the temperature at all, because the ground is in long term equilibrium with the atmosphere, (resulting in a temperature of about 10°C for this country). Soil temperature can be viewed as a daily or annual wave, whose amplitude is damped to zero at a particular depth depending on the thermal properties of the soil. This depth is typically 10-14 m for the annual wave, and 1 m for the daily wave in most soils. Thus we have a constant temperature at approximately 10 m and a surface temperature which varies according to the season. In winter, this temperature is less than 10°C, leading to a general upward soil heat flux over this depth which depletes the the soil's heat store. In summer, the situation is reversed, with high surface temperatures forcing a downward flux of heat to build up the soil's heat store. Therefore, in spring and autumn there must be a time when the overall heat flux reverses direction, ie when the near surface temperature averages 10°C.

It seems reasonable to suppose then that during the course of this experiment a heat flux reversal would have taken place. At the start of the experiment, the 30 cm soil temperature under bare soil was 4.0°C and steadily rose to 10°C on day 112, albeit with some peaks and troughs along the way. Therefore at this point there is no net flux of heat between 30 cm and the deep soil. (The temperature wave has passed this level and the 10°C point is progressing downwards through the soil until eventually it reaches the depth of zero annual amplitude). The deep soil heat storage is then no longer contributing in a positive sense to the surface layers. Instead, it becomes a sink for the heat absorbed at the surface, so that whereas previously this top part of the profile had been warmed from below and above, (during periods of high insolation and warmer air temperatures), after the flux reversal it is only warmed from the surface, and loses some of this heat to the deep soil.

How does this concept of long term soil heat flux relate to the mulch? Because of the mulch, the soil temperatures in the uppermost layers have been artificially raised causing increased soil heating in these regions by day. Consequently the lower layers of the soil become a sink of heat more quickly than those not under the polythene, bringing forward the reversal of net heat flux between the surface the the zero amplitude level. At this stage the bare soil is still being warmed from below and the increased air temperatures and power of the solar radiation gives rise to some rapid soil temperature rises. For instance, Figure 7 shows that between day 104 and 116 the 30 cm soil temperature rose by 3.3°C, which is a sizeable increase for that depth. In the same period the 30 cm temperature under polythene also rose, but only by 2°C, so the difference, (see Figure 6,) declines and becomes negative. Is it coincidental that the 30 cm temperature difference becomes negative during the probable period of net soil heat flux reversal?

If Figures 6 and 7 are closely compared, it can be seen that from day 90 to 125, (mulch removal), the curves are a 'mirror image' of one another, ie when the difference declines, the temperature at 30 cm under bare soil rises, and vice-versa. (Of course, the temperature axes are scaled diffently, which highlights the effect, but that does not detract from the argument). The conclusion from this is that the bare soil temperature is the dominant component of the difference, while the mulch temperature fluctuations are suppressed. It would seem, therefore, that the soil under the polythene has effectively become 'decoupled' from the external influences, or at least is not responding to them as swiftly as the bare soil.

Perhaps the most surprising aspect of the soil temperature behaviour was that after removing the polythene, the temperature under where the mulch had been continued to become colder than the bare soil plot. Indeed, the fall was sharp at 30 cm, so that when recording ceased 16 days after the mulch was removed, the difference was 3.1°C, although viewed within the context of the general decline from day 100, the slope is not exceptional. Intuitively, one might have expected to see the temperature difference converge to zero almost immediately after removing the mulch, as it must presumably eventually do. The surface temperature difference instantly becomes zero as one might expect, but the 10 cm temperature difference becomes slightly negative, particularly in the late afternoon when the magnitude is approximately 1°C-2°C. Figure 5 shows this effect in the small decline in the accumulated temperature excess at 10 cm.

To properly put these observations into context, the circumstances in which the experiment was carried out should be examined. Firstly it is worth pointing out that end of the experiment the young carrots foliage would cover a fair proportion of the ground, and therefore one might expect a different temperature regime to exist underneath it, when compared to bare soil.

Secondly, the soil at Arthur Rickwood has a very high peat content, which implies that its thermal diffusivity is low. (See Appendix II for some explanations of soil heat theory). The consequence of this is that the effective depth of annual heat penetration is of the order of 3-5 m, and the daily depth is about 50 cm. Also because the heat capacity is large it takes a long time for peat to heat or cool relative to sand or clay.

Thirdly, the trial was carried out during a period of unusually low rainfall in April. From the 21st March, (day 80) to the 4th May (day 124), only 18.5 mm of rainfall was recorded. The surface layers of the bare soil plot were therefore quite likely to be very dry resulting in low values of thermal diffusivity. More importantly perhaps, the lack of surface moisture means that the incoming solar radiation is available to heat the soil and air instead of evaporating water from the soil, as in the case of the mulch. Unlike the mulch however the bare soil is directly exposed to the effects of air movement, and consequently loses heat by convection. This lack of rainfall argument does of course assume that the soil under the mulch remains moist. Unfortunately, no observations of the soil state were made, so any effect due to low rainfall remains speculative.

Conclusions

The use of clear polythene as a 'floating mulch' produced excess daytime temperatures up to 15°C, and these led to a doubling of the accumulated temperature above 6°C at the surface, as compared to an unmulched plot.

The polythene mulch provided little or no temperature advantage during the night. Growers intending to use polythene mulches to protect frost sensitive plants in the spring should note this.

Soil temperatures under the mulched plots were observed to decline relative to the bare soil plots after the polythene was removed. Indeed, the 30 cm soil temperature difference went into decline well before the removal, and became negative 14 days prior to the event. However, it is only fair to point out that a better comparison would have been against a control plot of growing carrots experiencing more normal spring rainfall.

The question of the moisture retention, and net evaporation losses from the polythene mulch needs to be firmly established before a conclusive understanding of the problem can be reached. If the experiment were to be repeated it would be worth making some observations of the soil moisture state during and after the experiment.

It is not possible, based on these observations, to invoke any meteorological parameter in order to decide the optimum time for mulch removal, unless the 30 cm soil temperature is important. That is not to say that the plant's physiology is not affected by the modified temperature and radiation, however, and so these variables could indirectly suggest an optimum removal time.

Care should be taken in extrapolating these results to other sites particularly with regard to soil temperatures because of the large differences between the thermal properties of peat and sand or clays.

References

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APPENDIX I

For those readers who are interested, equations for the heat fluxes are set out below. Notice that they all have the following form:

Flux of an entity = Ability of the medium to transport the entity x Gradient of a relevant property

Notice also that the expressions for H and G directly include the surface temperature.

$$\text{Sensible heat flux, } H = -\rho c_p K_h \left(\frac{T_a - T_s}{\Delta z} \right)$$

$$\text{Latent heat flux, } LE = -\rho L_v K_w \left(\frac{q_a - q_s}{\Delta z} \right)$$

$$\text{Soil heat flux, } G = - K_s \left(\frac{T_s - T_a}{\Delta z} \right)$$

The following are variables;

T_s = surface temperature

T_a = air temperature

Δz = depth over which the temperature difference is calculated

q_a = specific humidity of the air

q_s = specific humidity at the surface

The remaining quantities are all constants;

ρ = density of air

c_p = specific heat capacity of air

L_v = Latent heat of vaporisation

K_s = thermal conductivity of soil

K_h = 'eddy conductivity'

K_w = 'eddy diffusivity for water vapour'

APPENDIX II

The thermal properties of a soil are described by its thermal conductivity, k, and its specific heat capacity, c . k is a measure of the soil's ability to transport heat, and c is a measure of its ability to store heat. Both are strongly dependent on the amount of water in the soil, because the thermal properties of water are very different to that of air, which water replaces in a soil if it becomes wet.

The best parameter to describe a soil's thermal properties is a combination of k and c , called the thermal diffusivity, and is given by,

$$K = \frac{k}{\rho c}$$

Thermal conductivity increases with water content until saturation, but thermal diffusivity usually reaches a peak at 20% water content by volume, because after this point the increasing heat capacity more than counterbalances the increasing conductivity.

The values for diffusivity, in units of 10^{-6} $m^2 s^{-1}$, are as follows;

Water Content	Sandy Soil	Clay Soil	Peat Soil
0%	0.24	0.18	0.10
20%	0.85	0.53	0.13
40%	0.74	0.51	0.12

Observe how markedly different peat is to sand and clay when it becomes wet.

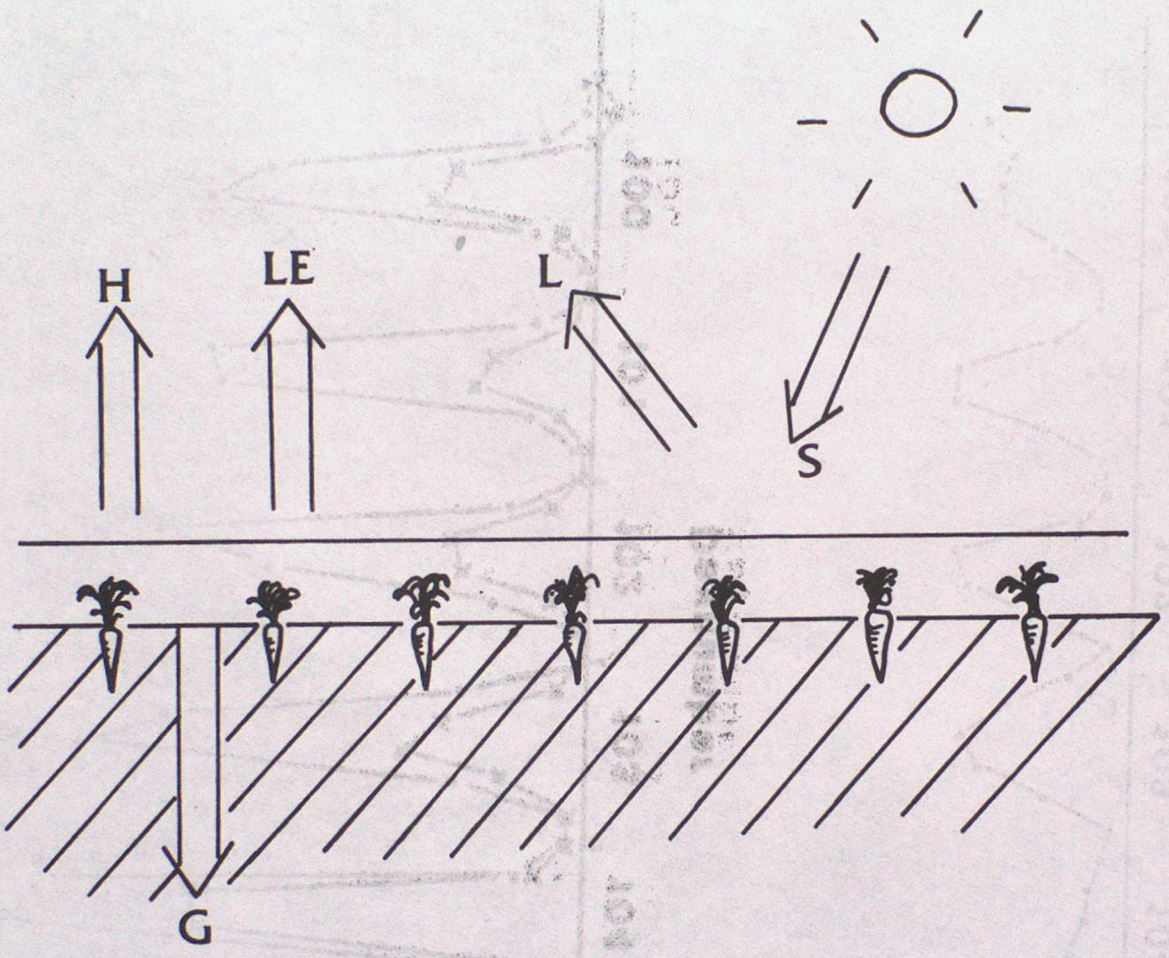
If it is assumed that the temperature at the soil - air interface oscillates sinusoidally during a daily or annual cycle, then it is possible to derive expressions for the amplitude of this oscillation, and how far into the soil it penetrates. It can be shown, for example see Monteith (1973), that at a depth z = D, the amplitude of the temperature wave is 1/e, (= 0.37), times the amplitude at the surface. That is to say, the amplitude decays exponentially down the profile, which seems reasonable. D gives a good indication of how the depth of zero amplitude varies between the types of soils. Knowing the values for thermal diffusivity, D can be calculated for the annual and daily cycles:

Soil	Annual Cycle	Daily Cycle
Peat (20% water)	0.8 m	3 cm
Clay (20% water)	2.6 m	13 cm
Sandy (20% water)	3.6 m	18 cm

Again, observe how drastically different peat is to sand and clay.

(N.B. The damping depth, D, is not the same as the depth of zero amplitude).

Figure 1. Contributions to the Surface Energy Budget.



S the net solar radiation impinging on the surface. (ie. the sum of downward direct and diffuse radiation, and upward reflected radiation.)

L = the long-wave emission of radiation.

R_N = S + L (net radiation)

H = the sensible heat flux.

LE = the latent heat flux.

G = the soil heat flux.

Figure 2. 4 hour averages of surface temperature excess, solar radiation and windspeed.

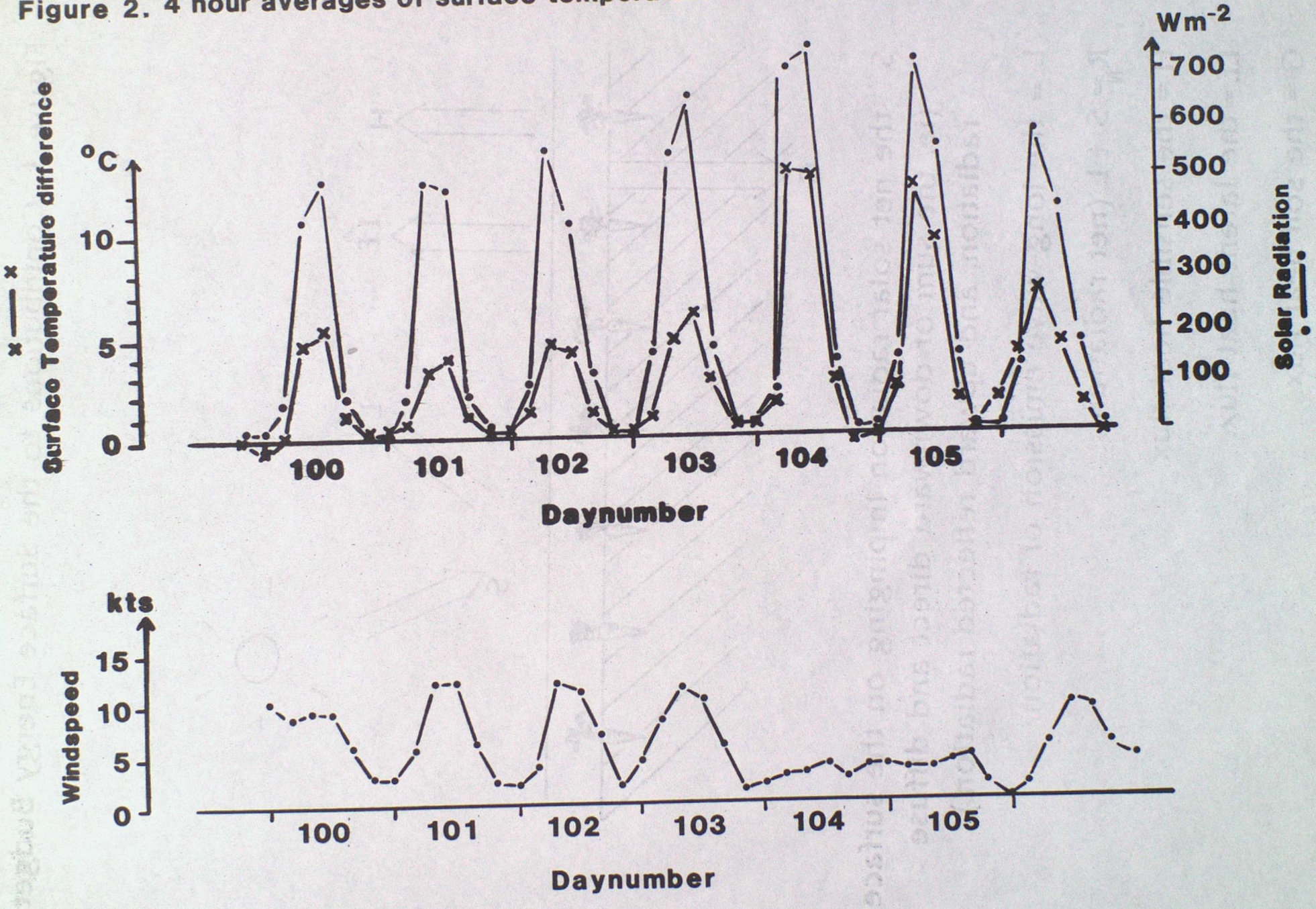


Figure 3. Further 4 hour averages of surface temperature excess, solar radiation and windspeed.

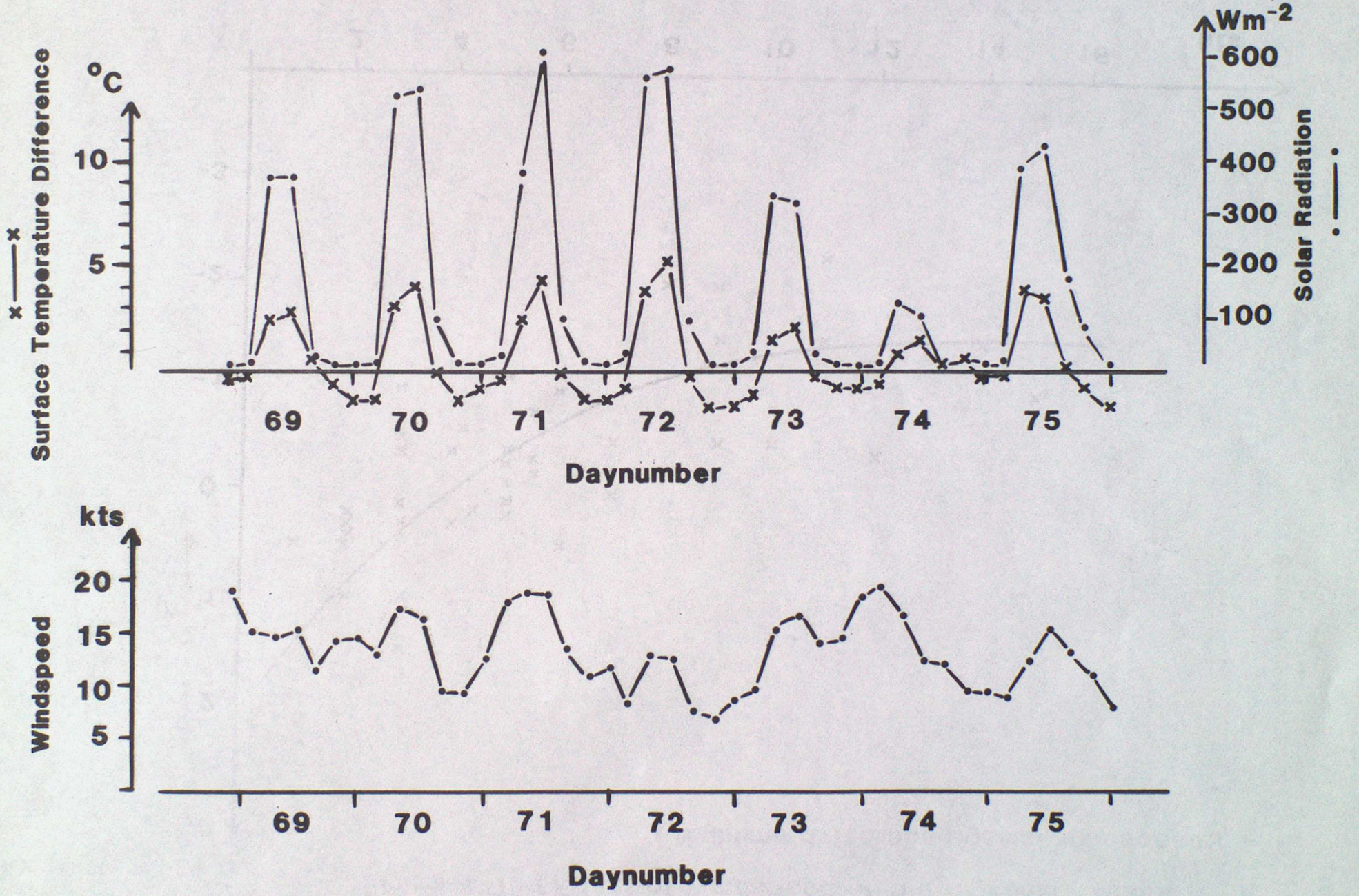


Figure 4 The Effect of Windspeed on the Nightime Excess.

(Nightime difference against windspeed)

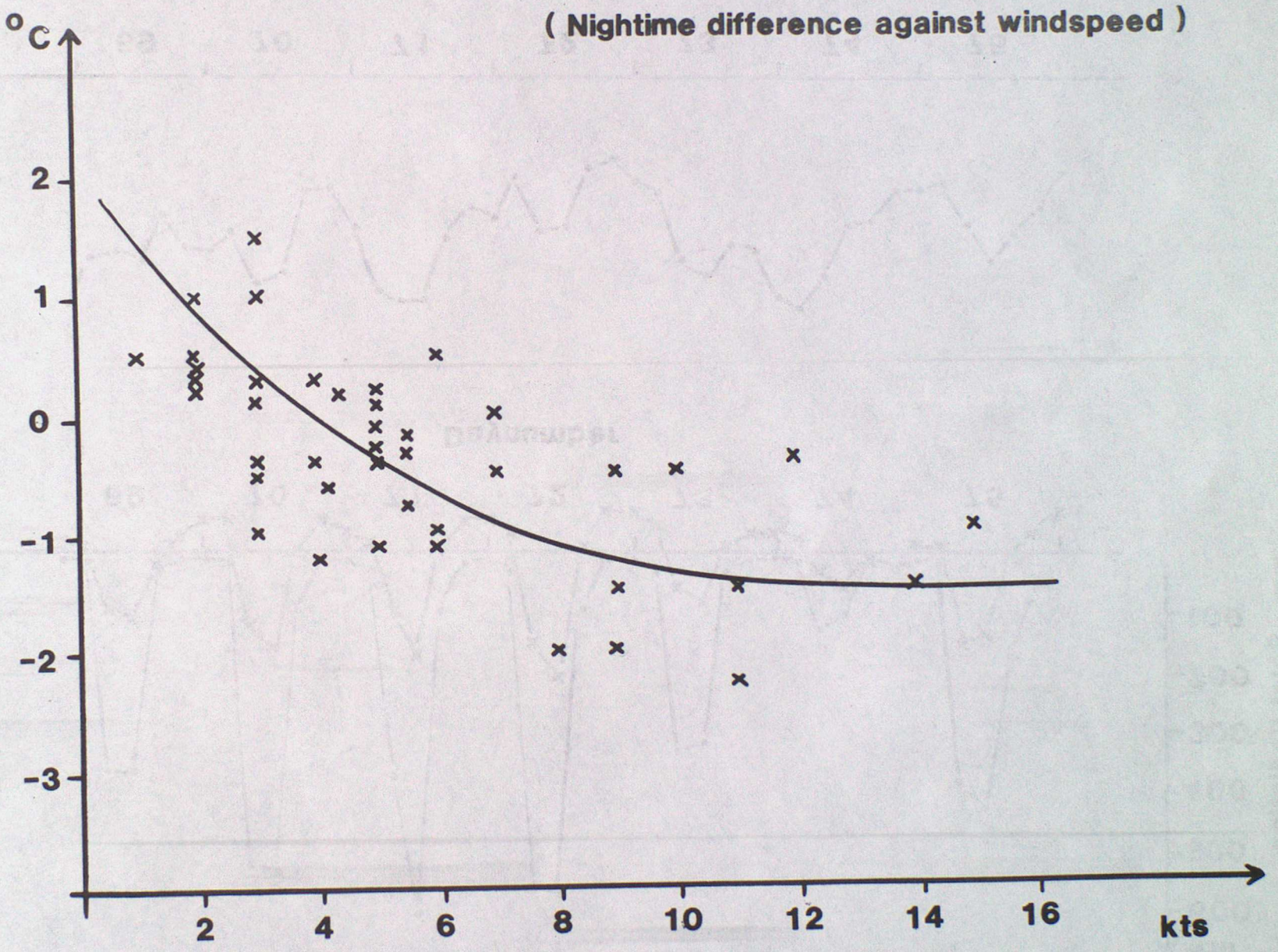


Figure 7. The actual 30cm soil temperature in the bare soil plot.

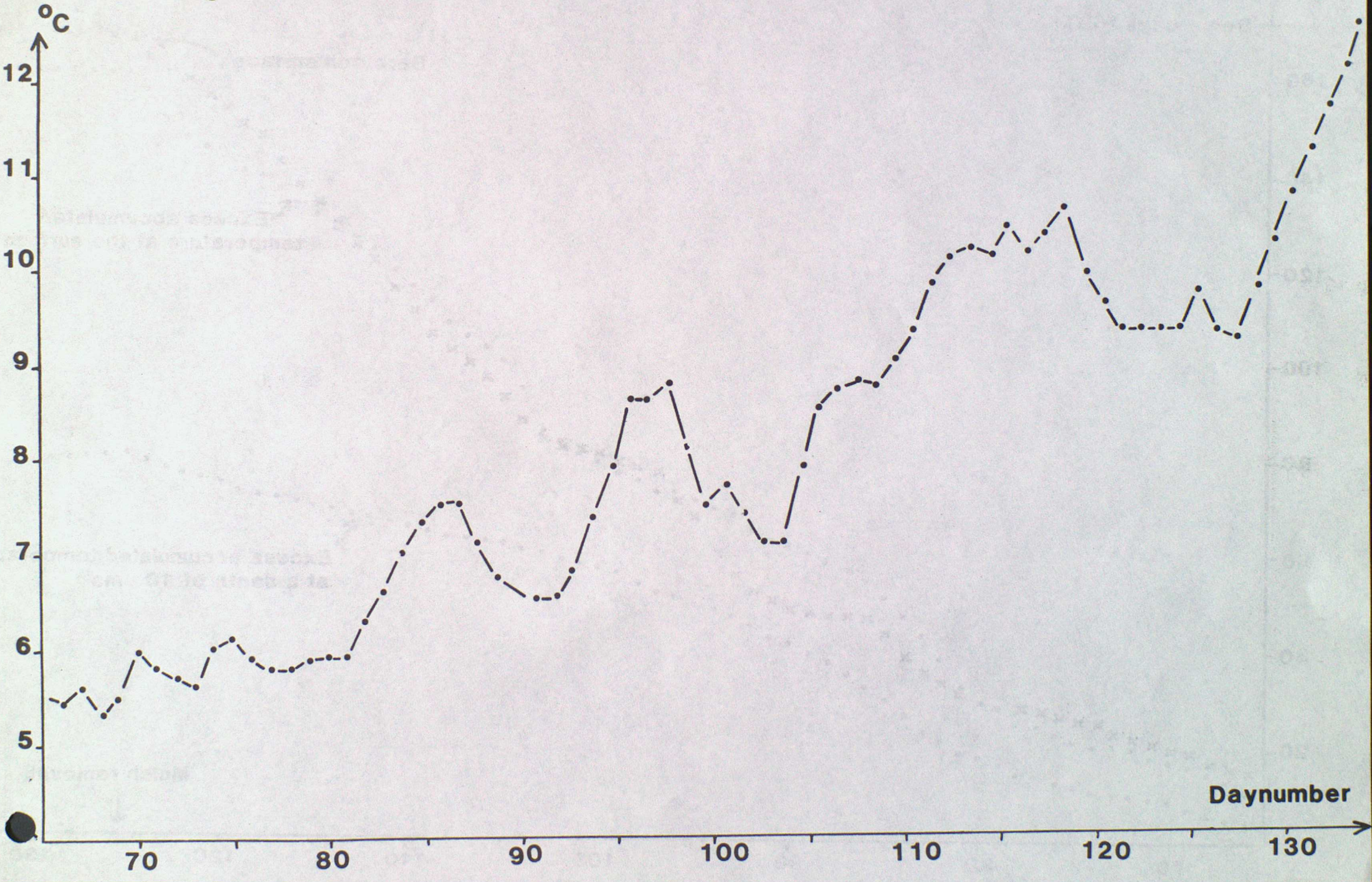


Figure 5 . Accumulated temperature above 6°C

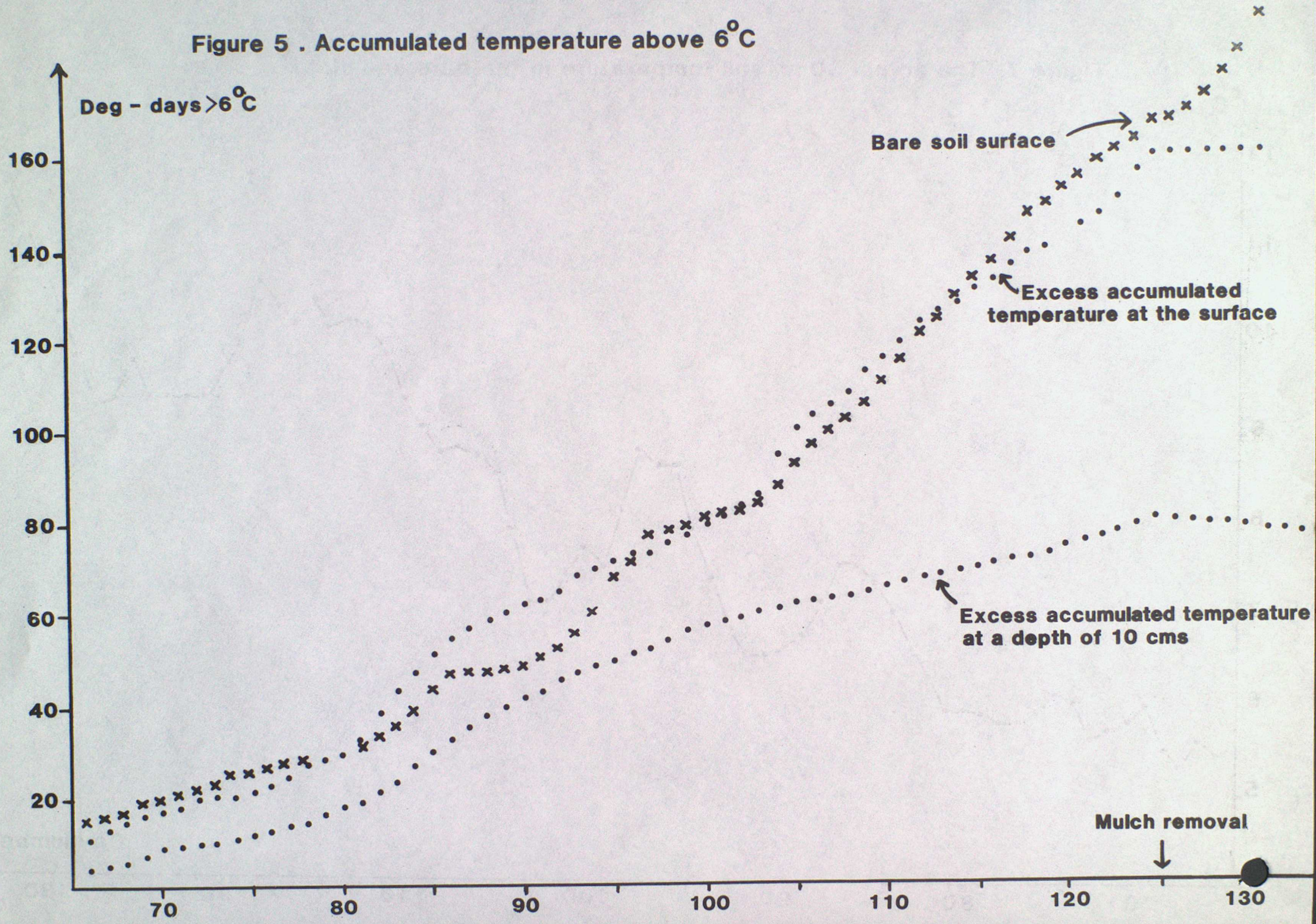


Figure 6. The soil temperature difference at 30cm between the mulch and bare soil.